Habitat Equivalency Analysis: An Overview

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1. Introduction

1.1 Goals of the paper

Natural resource trustees are authorized to act on behalf of the public to protect the resources of the nation's environment. Serving as a trustee for coastal and marine resources,[1] NOAA determines the damage claims to be filed against parties responsible for injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury such as vessel groundings. Habitat equivalency analysis (HEA) is a methodology used to determine compensation for such resource injuries. The principal concept underlying the method is that the public can be compensated for past losses of habitat resources through habitat replacement projects providing additional resources of the same type. Natural resource trustees have employed HEA for groundings, spills and hazardous waste sites. The habitats involved include seagrasses, coral reefs, tidal wetlands, salmon streams, and estuarine soft-bottom sediments.

The goals of this paper are to present an overview of HEA and illustrate the method with a simple, hypothetical example. In section 1.2 below, we outline briefly the natural resource damage context for HEA applications and the conditions for use of HEA. An example of how HEA is used to estimate the appropriate level of compensation for injuries to natural resources is presented in section 2. Appendices A through C present an algebraic representation of the HEA calculations and provide detailed tables from the example.

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[1] The Under Secretary for Oceans and Atmosphere (NOAA Administrator) acts on behalf of the Secretary of Commerce as a Federal trustee for natural resources under the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), the Clean Water Act, the National Marine Sanctuaries Act, and the Oil Pollution Act of 1990.

1.2 Use of HEA in natural resource damage assessments

Natural resource damage claims have three basic components: (1) the cost of restoring[2] the injured resources to baseline,[3] "primary restoration," (2) compensation for the interim loss of resources from the time of injury until the resources recover to baseline[4] *plus* (3) the reasonable costs of performing the damage assessment. Following statutory requirements, all recovered damages are used to restore, replace, rehabilitate or acquire the equivalent of the injured resources (or to cover the costs of assessments). Consequently recoveries for interim losses are spent on "compensatory restoration" actions providing resources and services equivalent to those lost. To ensure full compensation for interim losses, the trustees determine the scale of the proposed compensatory restoration actions for which the gains provided by the actions equal the losses due to the injury. The damage claim then is the cost of implementing the selected primary and compensatory restoration actions (plus the costs of the assessment). To develop the restoration plan, trustees must determine and quantify injury, develop restoration alternatives that consist of primary and compensatory actions, scale restoration alternatives, and select a preferred restoration alternative. This paper examines a method for scaling restoration alternatives, habitat equivalency analysis.[5]

For compensatory restoration actions, the scaling question is: what scale of compensatory restoration action will compensate for the interim loss of natural resources and services from the time of the incident until full recovery of the resources? The question makes clear that the scale of compensatory restoration actions is conditional upon the choice of primary restoration actions.

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[2] Restoration refers to human actions taken after the removal of the cause of injury (e.g., after remediation of a hazardous waste site, removal of the vessel in the event of a grounding), to return an injured resource to its pre-injury conditions. We use the term in its broad sense, to encompass the statutory concepts of "restoration, rehabilitation, replacement, and/or acquisition of the equivalent" of the injured resources.

[3] At any point in time, baseline refers to the condition the site would have achieved at that point in time, *but-for* the injury.

[4] If the resources are not expected to recover fully, interim losses will be calculated in perpetuity.

[5] This description characterizes the process outlined in the natural resource damage assessment (NRDA) regulations implementing the Oil Pollution Act and in the proposed statutory changes to the Superfund NRDA provisions.

Consequently, for each restoration alternative under consideration, the type and scale of the primary restoration actions are to be identified first.[6] Then the compensatory components of restoration alternatives can be scaled.

As noted above, the process of scaling a project involves adjusting the size of a restoration action to ensure that the present discounted value of project gains equals the present discounted value of interim losses. The two major scaling approaches are the valuation approach and the simplified service-to-service framework which applies under certain conditions.

HEA is an example of the service-to-service approach to scaling. The implicit assumption of HEA is that the public is willing to accept a one-to-one trade-off between a unit of lost habitat services and a unit of restoration project services.[7] There is not necessarily a one-to-one trade-off in resources but instead in the services they provide. For example, consider stem density as the resource and productivity the associated service. Suppose the replacement project provides only 50 percent of the productivity per unit of stem density that the injury site provides. Habitat equivalency analysis is applicable so long as the productivity services are comparable. In order to restore the equivalent of lost productivity per year, then, the replacement site just requires twice as many stems.

The assumption of comparable services between the lost and restored habitats may be met when, in the judgment of the trustees, the proposed restoration action provides services of the same type and quality, and of comparable value as those lost due to injury. In this context, the scaling analysis simplifies to determining the scale of a restoration action that provides a quantity of discounted replacement services equal to the quantity of discounted services lost due to the injury.

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[6] This includes identifying the recovery trajectory from primary restoration.

[7] The concept of services refers to functions a resource serves for other resources and for humans. For example, a wetland habitat may provide on-site ecological services such as faunal food and shelter, sediment stabilization, nutrient cycling, and primary productivity. Off-site services may include commercial and/or recreational fishing, bird watching along the flyway, water quality improvements due to on-site water filtration, and storm protection for on-shore properties due to the creation of wave breaks. Human services include both use and non-use services, so the HEA approach measures and accounts for non-use services in the damage claim.

In cases where services at the compensatory restoration site are not of the same type and quality or of comparable value to those injured, then the assumption of a one-to-one trade-off between the resource-based metric for services at the injury site and the compensatory restoration site may be inappropriate. In these cases, NOAA recommends that trustees evaluate whether the conditions for HEA are met and consider using valuation methods as an alternative for determining the trade-off between injuries and compensatory restoration actions.

Necessary conditions for the applicability of HEA include that (1) a common metric can be defined for services that captures any significant differences in the quantities and qualities of services provided by injury and replacement habitats, and (2) the changes in resources and services (due to the injury and the replacement project) are sufficiently small that the value per unit of service is independent of the changes in service levels.[8] To evaluate the quantity and quality of services provided per unit of habitat, the trustees are to examine the *on-site characteristics* and *landscape context* of the habitat resources and services. On-site biophysical characteristics determine the *capacity* of an ecosystem to provide ecological and human services. Landscape context affects whether the ecosystem will have the *opportunity* to supply many of the ecological and human services and strongly influences whether humans will *value* the opportunities for services.

The choice of a metric to characterize services is key to the evaluation of the applicability of HEA in a given context. On-site ecological attributes, such as stem density, canopy structure (density times height), or fish density, are sometimes used as a proxy for services; however, they primarily are indicators of capacity. It is critical to evaluate the role of landscape context to evaluate the opportunity to provide off-site, as well as on-site, ecological and human services.[9]

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[8] A counterexample shows when this condition is not satisfied. Consider the value of harvesting another salmon when salmon are in abundant supply versus the value of another salmon when the harvest has failed in Alaska. The value of providing another pound of salmon may be substantially greater when the salmon are in scarce supply, all else equal.

[9] For a further discussion of these issues, see, *Scaling Compensatory Restoration Actions, Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990,* National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Public Review Draft, 1997. In particular see pages 2-3 - 2-6 and 2-11 - 2-14.

2. Habitat Equivalency Analysis: An Example

In this section we provide a simplified example to illustrate the method. To complement the example, we provide the algebraic formula for solving an HEA in Appendix A.

We construct the following hypothetical scenario. A 4,047 square meter seagrass bed composed entirely of *Syringodium* has been completely destroyed by a ship grounding in the beginning of 1995.[10] Injury impairs the function of the habitat; the seagrass provides shelter and food for animals. In addition, the loss of seagrass affects human services. On-site sediment stabilization and nutrient filtration from seagrass provides storm protection and water quality enhancement, respectively. Seagrass habitat also supports off-site human services through recreational and commercial fish catch.

Trustees identified a feasible restoration action for compensation: transplanting *Syringodium* at the injury site for primary restoration and at a nearby site for compensatory restoration. The projects are expected to restore the same type and quality of resources and services. Further, given the similar landscape context of the injury and restoration sites, the trustees judged the projects would restore resources and services of comparable value as those lost.

Under these conditions, HEA applies as a framework for scaling compensatory restoration. The basic steps for implementation include:

1. Document and estimate the duration and extent of injury, from the time of injury until the resource recovers to baseline, or possibly to a maximum level below baseline;
2. Document and estimate the services provided by the compensatory project, over the full life of the habitat;
3. Calculate the size of the replacement project for which the total increase in services provided by the replacement project equals the total interim loss

[10] The size of the injury is completely arbitrary and chosen simply to demonstrate the calculation process.

of services due to the injury; and

4. Calculate the costs of the replacement project, or specify the performance standards in cases where the responsible party will be implementing the compensatory habitat project.

In the first two steps, trustees must specify numerical values for ecological parameters for both the injured site and the compensatory project site. For each point in time at both sites, the level of services must be characterized as a percent of the baseline level of services at the injured site. As previously noted, the baseline of services is the level of services that would have been provided at the injured site *but-for* the injury. In our example, service levels for the injured site and for the compensatory project site are a function of the baseline shoot density of *Syringodium*.

In step three, we calculate the size of the compensatory project for which the total increase in services provided by the replacement project just equals the total interim loss of services due to the injury. Because losses and gains are occurring in different years into the future, we apply a discount rate to translate all of the terms into a comparable basis - what they are worth in the present year, 1995. The discount rate incorporates the standard economic assumptions that people place a greater value on having resources available in the present than on having their availability delayed until the future. [This process is analogous to financial calculations where, if I put a dollar in the bank today at 3% interest, I will have $1.03 in one year. I am willing to deposit money in such an interest bearing account only if having $1.03 is (at least) as good as having $1 today.]

The annual discount rate used in a HEA calculation represents the public's preference towards having a restoration project in the present year, rather than waiting until next year. The economics literature supports a discount rate of approximately 3%.[11]

We list below the parameters necessary to complete a simple HEA.

Injured Area Parameters:

- Baseline level of services at the injury site**;**
- Extent and nature of the injury: the spatial extent of injury (in square meters for example) and the initial reduction in service level from baseline at the injured site (characterized as a percent of the baseline level of services). These parameters may be combined to measure the "effective-square meters" of an injury;[12]
- Injury recovery function (with primary restoration or natural recovery): functional form of the recovery and the maximum level of services to be achieved (characterized as a percent of the baseline level of services);
- Recovery period for injured resources: the dates when recovery starts and when maximum level of services will be achieved.

Replacement Area Parameters:

- Initial level of services at the replacement project site, as measured in effective-area (as a percent of baseline services at injury site);
- Replacement project maturity function: the rate of (incremental) service growth and the maximum level of services at the replacement project site (as a percent of the baseline level of services at injury site);
- Recovery period for injured resources: the dates when services begin to increase and when the maximum level of services will be achieved;
- Replacement/creation project duration: lifetime of increased services.

Time-Equivalency Parameter:

- Annual real discount rate

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[11] See for example, A. Myrick Freeman, (1993) *The Measurement of Environmental and Resource Values: Theory and Methods. Resources for the Future,* Washington D.C.

[12] Effective-square meters may be illustrated with an example. If 30% services remain on an injured 100 square meter site, the injury totaled 70 effective-square meters (100 * (1-0.3) = 70). Note that the percent is represented by its decimal equivalent.

In the following section, we walk through the each of the steps to HEA and show how ecological parameters are developed from the injury and how the HEA equation is solved.

Step 1: Quantifying the losses from the injury. For our example, parameter values characterizing the injury are listed in the table below. As shown, we denote the complete destruction of 4,047 square meters of *Syringodium* seagrass by specifying that 4,047 square meters provide 0% services relative to baseline at the time of the injury (1995). The site is projected to maintain a 0% service level until the primary restoration project (transplanting *Syringodium* at the injury site) is completed in 1997. The injured area is then projected to recover in two years following a linear growth path to baseline.[13]

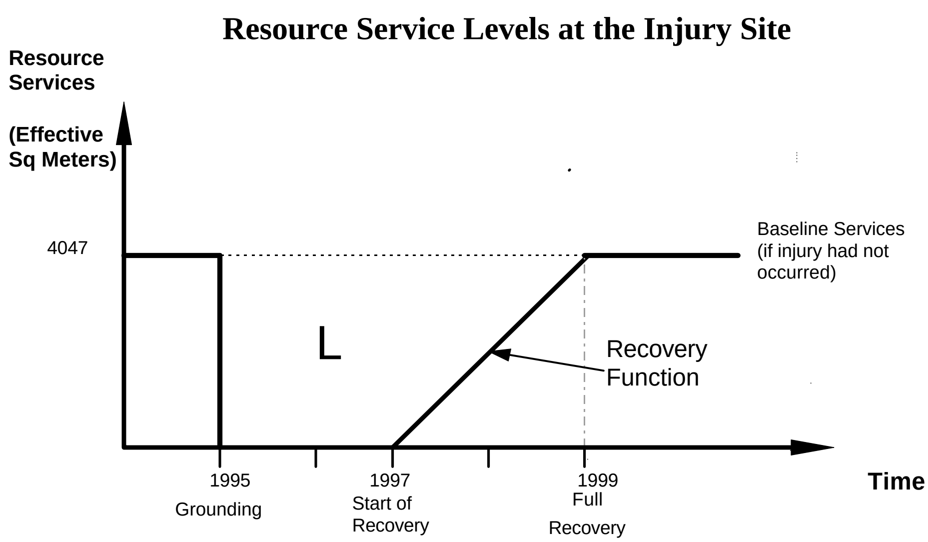
Table 1: Injury Parameter Values

Baseline Information of the Injured Resource:	
Habitat type injured:	Seagrass
Year of injury	1995
# of injured square meters:	4,047
Level of services in injury year (relative to baseline services):	0%
Recovery of Injured Habitat following Primary Restoration:	
Year restoration project ends and recovery starts:	1997
Years until full recovery:	2
Services at maximum recovery (relative to baseline):	100%
Shape of recovery function:	Linear
Time-Equivalency Parameter:	
Real annual discount rate	3.0%

[13] We assume this recovery function to simplify the presentation. An alternative recover function such as a constant growth rate could also have been incorporated.

The recovery of services provided by the injured habitat is illustrated in the following diagram. On the vertical axis is the level of services provided by the injured resource, measured in "effective-square meters". The effective-square-meters of services for a given year represents the product of the percent of baseline seagrass services provided by a square meter of the injured site times the number of square meters injured.[14] When the injury occurs, in year 1995, the number of effective-square meters of services drops from 4047 to 0, because 0% services remain at the site. Services increase along a linear path beginning in 1997, until full recovery to the baseline in 1999. Interim losses are represented in the diagram by the area labeled "L".

Figure 1:



To calculate the measure of interim loss in present value terms, we must apply the yearly discount factor to the losses in each year. We calculate an interim loss of 11,763 discounted effective-square meter-years by summing over all years of the injury. Appendix A presents the specific steps for calculating the discounted interim loss in services.

[14] In the multiplication, the percent is represented by the decimal equivalent, so the baseline level of effective square meters is 1.00*4,047. In 1998, the site is projected to operate at 50% of baseline, so the effective service level is .5 * 4,047 = 2023.5.

Step 2: Quantifying the gains from the habitat replacement project. The parameters characterizing the habitat creation project are listed in the table below. Prior to the project, seagrass does not grow on the site; in other words, the site offers 0% seagrass services. The transplanting project begins in 1997 and ends in year 1998 (after transplanting has been completed). We project that seagrass services increase during a 2-year growth period along a linear path and reach a maximum service level in year 2000 that is 100% of the baseline service level of the injured site. We further project that the site will continue to function at the maximum service level in perpetuity.

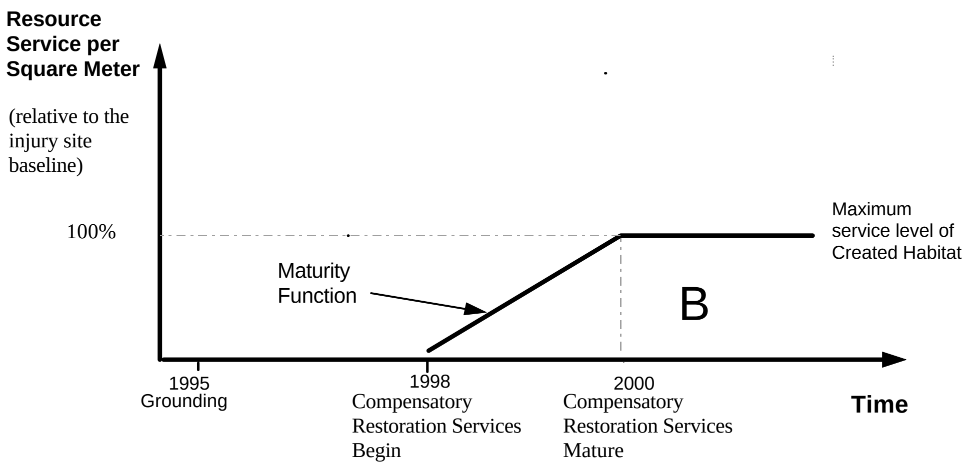
Table 2. Replacement Project Parameters

Replacement Project Characteristics	
Replacement habitat type:	Seagrass
Initial level of services	0%
Year creation/replacement project starts	1997
Year services start increasing	1998
Year in which maximum service level is reached	2000
Maximum service level	100%
Shape of recovery function	Linear
Expected length of service increase	Infinity
Replacement Project Comparison Parameter	
Ratio of maximum services per square meter at the compensatory site and the baseline services per square meter at injured habitat.	1:1

The increase of services at the habitat creation site is illustrated in the following diagram. The vertical axis measures the increase in services per square meter of a replacement project as a percent of the baseline services per square meter at the *injured site*. As shown, services increase in year 1998, following a linear path until the services reach full maturity in year 2000; these services continue to function at the maximum level in perpetuity. The total increase in services per square meter is shown as the area “B”.

Figure 2:

Resource Service Levels at Replacement Project Site



To calculate service gains in the present value terms, we must apply the yearly discount factor to the gains in each year, which are represented in the diagram, and sum over the lifetime of the replacement project. This calculation, presented in more detail in Appendix B, indicates that each square meter of replacement project provides 30.51 discounted effective-square meter-years of services.

Step 3: Determining the Size of the Replacement Project. To calculate the size of the compensatory project needed to compensate for the losses, we divide the total loss in discounted effective-square meters-years by the gain per square meters of replacement, as outlined in Table 3.

Table 3. **Determining the Size of a Project to Compensate for Interim Losses**

- Injured Area = **4,047** m^2

Present discounted interim losses = **11,763** effective-square meter-years (See Appendix B)

- Present discounted lifetime gains per sq. meter of replacement project = **30.51** effective-square-meter-years per sq. meter (See Appendix C)
- Let **R** = # sq. meters of replacement habitat required for compensation.
- Equating lost services and replacement project gains:

  11,763 lost effective-m^2-years = **30.51** effective-m^2-years/ m^2 * **R** m^2

- *Solving for the size R of the replacement project yields:*

  R = 11,763/30.51

  = **385** m^2 of replacement habitat

Step 4: Calculating the Cost of the Replacement Project. Step four of HEA occurs after the trustees have calculated the scale of the project. The damages claim is based on the costs of replacement project[15]. Categories of project costs include the following:

- planning and design
- environmental impact assessment
- permitting
- construction
- monitoring
- mid-course corrections

Some of the categories of cost can be characterized on a per-square meter basis; others impose substantially high fixed costs (permitting). We do not calculate project costs in this example.

[15] Alternatively, the responsible parties may perform the replacement project, subject to performance criteria established by the trustees. In that case, they pay trustees for their monitoring costs.

Appendix A: Algebra of HEA

Below, we outline the generic formula employed to calculate the appropriate scale of the compensation project. We first provide the notation for the HEA calculations.

Let t refer to time (in years), where the following events occur in the identified years:

$t=0$, the injury occurs

$t=B$, the injured habitat recovers to baseline

$t=C$, the claim is presented

$t=I$, increment in services from habitat replacement project begins

$t=M$, habitat replacement project reaches full maturity

$t=L$, habitat replacement project increment in services ends

Other variables in the analysis include:

x_t^j , the level of services per square meter provided by the injured habitat in the beginning of year t

b^j , the baseline (without injury) level of services per square meter of the injured habitat[16]

x_t^p, the level of services per square meter provided by the replacement habitat in the beginning of year t

b^p, the initial level of services per square meter of the replacement habitat

r_t , discount factor, where $r_t = 1/(1+r)^{t-C}$, and r is the discount rate for the time period

J, the number of injured square meters

P, the size of the replacement project

[16] We simplify the representation of the baseline to be constant through time. Seasonal or inter-annual (or other) forms of variation could be incorporated, by adding time subscripts to the baseline variable *b*.

We select a metric, x, for capturing overall level of habitat services, or habitat function, which could represent a single service flow from the resource or an index that represents a weighted average of multiple service flows. In the chosen metric, we define: x_t^j as the level of services per square meter provided by the injured habitat in the beginning of year t, and b^j as the baseline level of services of the injured habitat; consequently, $(b^j - x_t^j)$ is the extent of injury in year t. Analogously, we define x_t^p, as the level of services provided by the replacement habitat in the beginning of year t, and b^p as the initial level of services of the replacement habitat, prior to any enhancement activities; consequently, $(x_t^p - b^p)$ represents the *increment* in resource services provided by the replacement project - which is the relevant measure for our analysis. In our discussion in the text in the body of this paper, however, we referred to habitat services as a percent of the baseline level of services of the injured habitat, b^j; in this format, $(b^j - x_t^j)/ b^j$ represents the percent reduction in services per square meter at the injured site from the injured site baseline, and $(x_t^p - b^p)/b^j$ represents the percent increase in services per square meter, relative to the injured site baseline, for the replacement site.

To translate the quantity in year t into an effective quantity in the year of the claim, C, we apply the discount factor $r_t = 1/(1+r)^{t-C}$, where r is the annual discount rate. For simplicity we assume that the claim is presented in the base year ($C=0$, the year of the injury) so the term simplifies to $r_t = 1/(1+r)^t$. Finally, the number of injured square meters is J. The goal of the habitat equivalency analysis is to solve for the size of the replacement project, P.

The equation equating the sum of the present discounted value of the services lost at the injured site with the sum of the present discounted value of the services provided at the replacement site becomes:

$$\left[\sum_{t=0}^{B} r_t\left(b^j - x_t^j\right)/b^j\right] * J = \left[\sum_{t=I}^{L} r_t\left(x_t^p - b^p\right)/b^j\right] * P$$

The calculation to solve for the size of the replacement project then becomes:

$$P = \left[\sum_{t=0}^{B} r_t\left(b^j - x_t^j\right)/b^j\right] * J / \left[\sum_{t=I}^{L} r_t\left(x_t^p - b^p\right)/b^j\right]$$

Appendix B: Interim Losses from a Seagrass Grounding

The table below documents the injury and recovery of services on an annual basis and presents the sum of total discounted effective-square meter-years lost. The first two columns identify the year and the corresponding status of the primary restoration project. The third column identifies service levels at the injured site as a percentage of the site baseline. Note habitat services grow for two years following a linear recovery path, starting in 1997. Columns four and five present the percent service loss at the beginning of the year and the average annual percent losses, respectively. In column seven, effective-square meters lost per square meter are calculated by multiplying the average annual service loss per year (in column 5) times the discount factor (in column six). Effective-square meters lost each year are calculated in column 8 by multiplying the effective loss per square meter by 4,047, the number of square meters injured. For example, the average increase in services for 1997 was 25% of the baseline. In other words, the average loss in services per square meter was 75% or, in discounted terms, 71%. The discounted effective-square meters lost then is 2,861 (4,047 square meters * .71 discounted effective-square meters per square meter).

Interim Losses due to Seagrass Injury							
1	2	3	4	5	6	7	8
Year	**Proj. Status**	**% Service Level (Start of Year)**	**% Service Loss (Start of Year)**	**Ave. Annual % Service Loss**	**Discount Factor**	**Disc. Ave. % Services Lost / Sq Meter**	**Discounted Effective-Square Meters Lost**
1995		0%	100%	100%	1.00	100%	4,047.00
1996	(Primary Restn.)	0%	100%	100%	0.97	97%	3,929.13
1997	(Recovery Begins)	0%	100%	75%	0.94	71%	2,861.01
1998		50%	50%	25%	0.92	23%	925.89
1999	(Recovery Complete)	100%	0%	0%	0.89	0%	-
2000		100%	0%	0%	0.86	0%	-
2001		100%	0%	0%	0.84	0%	-
		Total Discounted Effective Square Meter-Years Lost =					**11,763.04**

Algebraic notation for table calculations (refer to Appendix A):

Column 3: $\frac{x_t^j}{b^j}$ at start year

Column 4: $\frac{b^j - x_t^j}{b^j}$ at start of year.

Column 5: $\frac{b^j - (x_t^j + x_{t+1}^j)/2}{b^j}$

Column 6: $r_t = \frac{1}{(1+r)^{t-1995}}$

Column 7: *Column 5 * Column 6*

Column 8**:** *Column 7 * J*

Appendix C: Service Gains from Compensatory Restoration Project

In the table below, the increase in services of the compensatory habitat is calculated per square meter of replacement project. The first two columns are the same as in Appendix B. The third column indicates the service level of the habitat for a given year as a percent of the baseline service level of the injury site. We multiply the average annual change in services per year (column four) times the discount factor to determine the total discounted effective-square meters per square meter per year. At the bottom of the table, the total discounted effective-sq. meter-years per square meter are summed.

Seagrass Service Increases due to Replacement Project

1	2	3	4	5	6
Year	**Project Status**	**% Service Gain (Start of Year)**	**Average Annual % Service Gain**	**Discount Factor**	**Discounted Effective-Sq. Meters per Sq Meter**
1995		0%	0%	1.00	0.00
1996		0%	0%	0.97	0.00
1997	**(Replacement Project Begins)**	0%	0%	0.94	0.00
1998	**(Service Increase Begins)**	0%	25%	0.92	0.23
1999		50%	75%	0.89	0.67
2000	**(Services Reach Maximum)**	100%	100%	0.86	0.86
2001	**(Services Continue in Perpetuity)**	100%	100%	0.84	0.84
2002		100%	100%	0.81	0.81
2003 - "Infinity"		100%	100%		27.10
	Total Gain in Discounted Effective-Sq Meters-years/Sq Meters =				**30.51**

Algebraic notation for calculations (Refer to Appendix A):

Column 3: $\frac{x_t^p - b^p}{b^j}$ where $b^p = 0$

Column 4: $\frac{(x_t^p + x_{t+1}^p)/2 - b^p}{b^j}$

Column 5: $r_t = \frac{1}{(1+r)^{t-1995}}$

Column 6: *Column 5* Column 4*